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Technique to Improve Throughput in A Cellular Communication System

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A Novel Technique to Improve Throughput in a Cellular Communications System

Abstract

On the air interface of a mobile communications system there are different methods to achieve a two way communication link. These methods are referred to as frequency division duplex (FDD) and time division duplex (TDD). Each duplex method is usually assigned to a different frequency band. Systems using TDD and FDD methods, as yet, do not share common radio resources. This invention describes one method for the TDD scheme to „borrow" vacant radio resources from the FDD band and thus increase the spectral efficiency. The quantity of additional capacity (throughput) is dependent on the distance between the base station of the TDD system and the base station of the FDD system which can use any multiple access technique. As an example multiple access methods used for the 3rd generation European mobile communication standard UMTS were taken to carry out simulations. They show that with approximately 30% load of the FDD system the coexistent, stand alone TD-CDMA/TDD system can have about 40% additional capacity borrowed from the FDD system assuming an ideally placed TDD cell and equally distributed mobiles linked to the FDD cell. The TDD cells can be combined with other multiple access schemes such as for example CDMA or TDMA.

1 Technical Field and Background of the Invention

This invention relates to the air interface for radio communications where additional information capacity can be gained by allowing the sharing of frequency bands between different air interfaces.

Recently the ETSI[1] has launched a new standard for the 3rd generation of mobile communications systems and agreements relating to a world standard IMT-2000 are expected soon. One driving motivation for these new standards is the growing demand for data services such as video, fax, Internet applications, etc. The accompanied variable data rates and packet-oriented services combined with limited radio resources make new demands to the air interface and the cellular architecture. Due to the latter circumstance the cell clustering of the future mobile communication system will at least consist of macro and micro cells. Where the macro cells will ensure the overall coverage whereas micro or pico cells will be used to cover hot spot areas, e.g. places such as hotels, airports, etc..

The frequency bands assigned to air interfaces for radio communications can be divided into two categories:

[1] European Telecommunications Standards Institute

A) Paired Bands assigned to FDD[2]
B) Unpaired Bands assigned to TDD[3]

Besides the definition of the duplex scheme there must also be some methods chosen to accommodate several users at the same time (multiple access methods). Regarding the feasibility of the idea being proposed it is important to point out that for the FDD system, in principle, any multiple access method can be applied. The same is valid for the TDD system, however the TDMA (time division multiple access) mode offers ideal conditions. The invention is elucidated on a system defined by a future mobile communications standard (in this case UMTS[4]). Hence in the subsequent section 2.1, as an example, wideband code division multiple access (W-CDMA) will be applied within the paired bands combined with FDD. For the unpaired band a combination of CDMA and TDMA for which the acronym TD-CDMA stands, is employed.

To take the wide operational field of the invention into account the following notations and abbreviations will be used throughout this paper.

Used Phrases	Used Abbreviations	Description
FDD cell	---	A cell of a mobile communications system with FDD as duplex scheme and any multiple access technique. The FDD cells are often used to ensure overall coverage and are therefore referred to as macrocells.
TDD cell	---	A cell of a mobile communications system with TDD as duplex scheme and any multiple access technique - preferable TDMA. The TDD cells are often of smaller dimensions and covering hot spot areas. Therefore they are usually referred to as microcells. This however is not a limiting constraint concerning the invention proposed in this pamphlet.
FDD mobile/user	MS_F	The mobile unit linked to the FDD system with not necessarily having a TDD option.
TDD mobile/user	MS_T	The mobile unit linked to the TDD system with not necessarily having a FDD option
Base station of the FDD cell	BS_F	The fixed part to serve the air interface of the FDD system. It is assumed to be in the center of the cell
Base station of the TDD cell	BS_T	The fixed part to serve the air interface of the TDD system. It is assumed to be in the center of the cell

[2] In order to achieve a two way communication (duplex) each direction must be separated to avoid self jamming. This separation can be done either in the frequency domain or the time domain. The first case is called frequency division duplex (FDD) and the latter time division duplex (TDD). For the transmission from the mobile station (MS) to the base station (BS), which is referred to as "uplink", FDD uses a different band for the link from the BS to the MS ("downlink"). Both bands are separated by a frequency band (duplex distance). With TDD transmission (Tx) and reception (Rx) is done in the same band but with time gaps (guards times) in between.
[3] See (2)
[4] Universal Mobile Telecommunications System

2 Technical Features and Novelty

A possible cell layout of a cellular mobile communication system incorporating different cell types is depicted in Figure 1. Usually the TDD cells and the FDD cells use different frequency bands in order to cope with inter network interference. However, radio resources allocated to a system but remain unused represents a waste of channel capacity especially when the coexisting system is at its maximal load. Handover[5] between both cell systems might not be allowed for two reasons:

a) the mobile station is not capable of accessing both schemes (no dual mode capability)
b) the cells might be run by different operators.

Therefore it is desirable to share bandwidth between coexisting systems. The major problem arising with channel borrowing techniques is that they cause additional interference in the system from which channel capacity is borrowed. Hence, the goal is to find strategies so that the additional interference does not affect communication links.

This invention describes channel borrowing techniques whereby avoiding destructive interference to the coexisting network. The gain is a higher data throughput and, hence, improved total bandwidth utilisation. Investigations prove the feasibility of this novel method. The fact of assuming smaller cells for TDD is not a limiting constraint. Within section 2.1 the principles of the idea are illustrated on a real system which is UMTS. Due to the wide operational field of this invention in sections 2.2 the operation is explained where the TDD cells only use CDMA to achieve multiple access.

[5] A handover or handoff permits mobility between cells by assigning a mobile station (MS) another cell offering better link conditions.

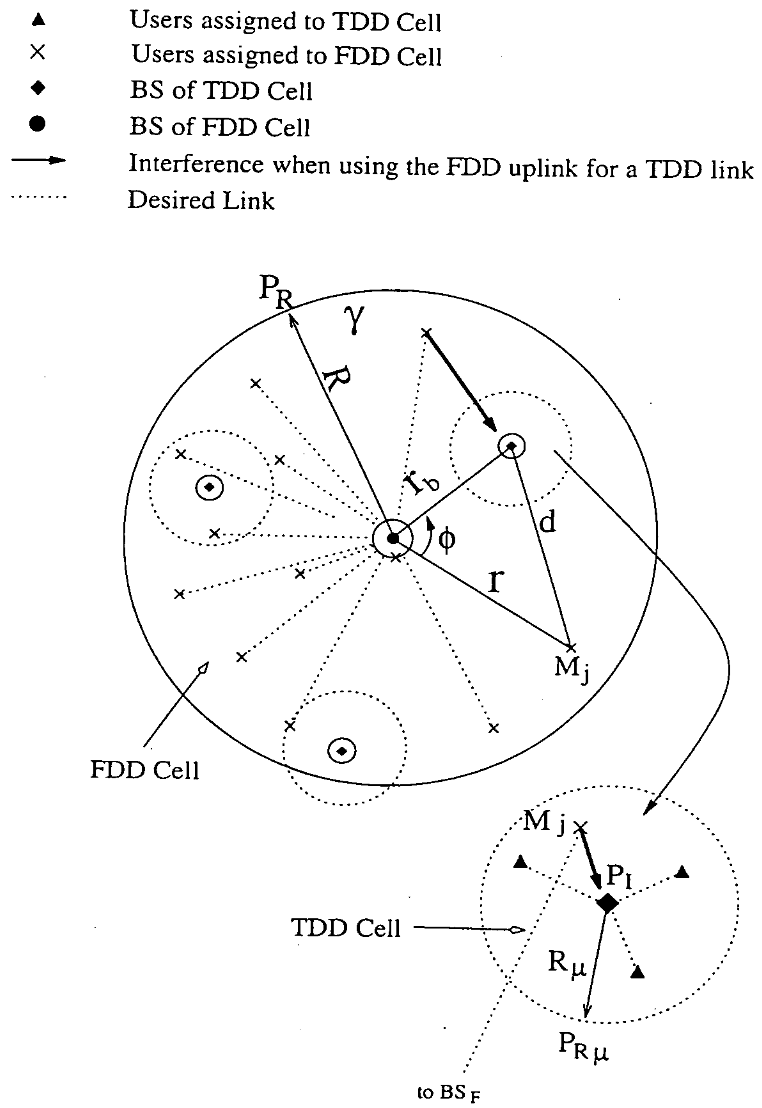

Figure 1: System Topology Assumptions

2.1 Illustrating the idea with multiple access techniques defined by UMTS

The European 3rd generation mobile telecommunications standard UMTS is utilising W-CDMA and TD-CDMA systems for FDD and TDD operation respectively. These schemes are used here as an example to illustrate the principles of operation, but other FDD-TDD systems could be used. The principles of both different methods W-CDMA and TD-CDMA are shown by Figure 2.

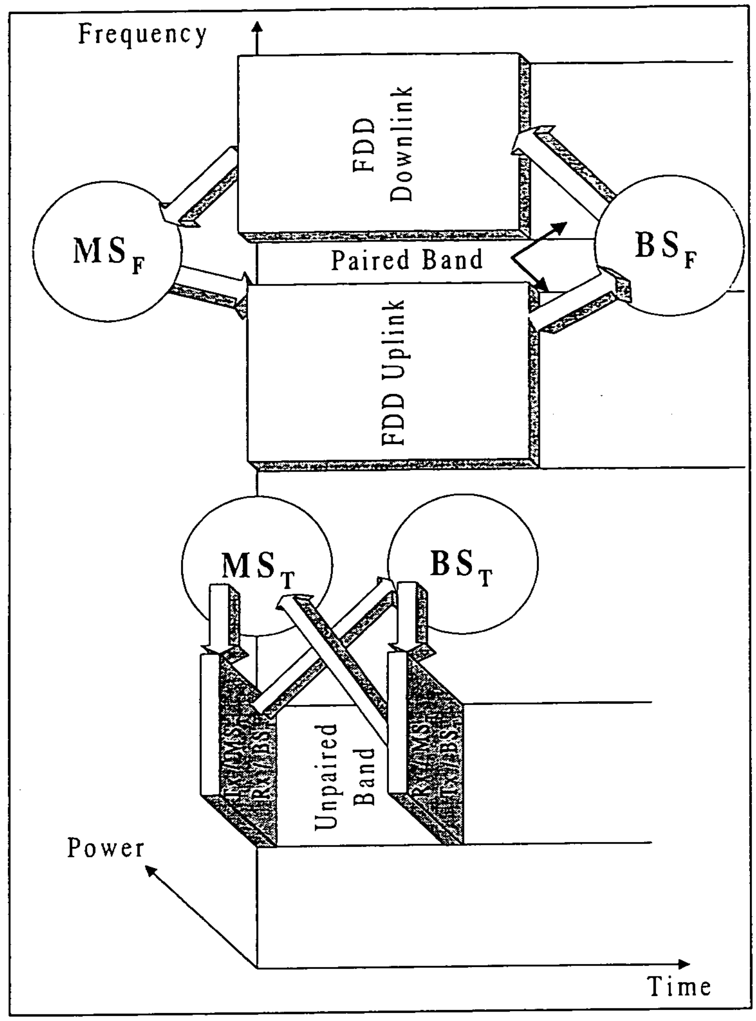

Figure 2: The principle of the multiple access and duplex methods used for the air interface of future mobile communications.

It is assumed that the base station of the TDD cell (BS_T) and the BS of the FDD cell (BS_F) are synchronised, i.e. the W-CDMA data frames and the TD-CDMA data frames are aligned.

The core idea of this invention is to use the uplink or downlink band of the FDD cell to provide additional capacity to TDD mobiles. The "borrowing" of capacity does not affect the FDD cell performance if the location of the BS_T is at a certain distance from the BS_F. The principles of this idea are shown in Figure 3.

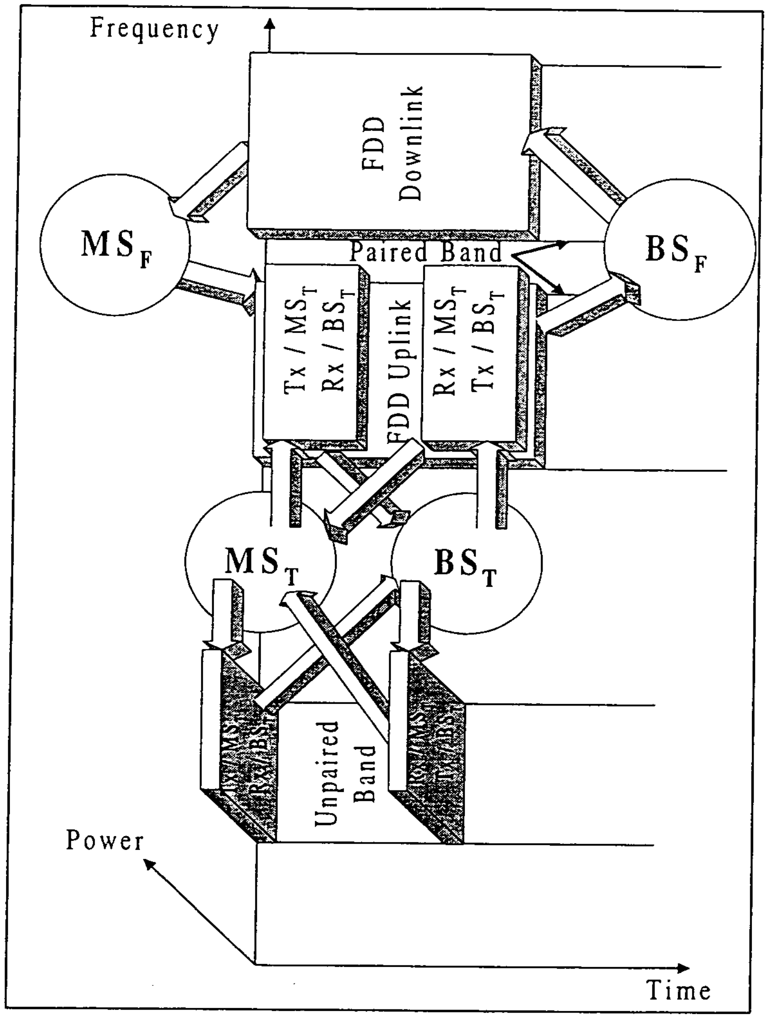

Figure 3: Exploiting the fact that the FDD uplink or downlink is not loaded at its maximum all the time the TDD cell, using the unpaired band, can make use of the FDD bands. For the sake of simplicity in this figure this is only shown for the FDD uplink. The same, however, can be applied for the downlink. A DCA (Dynamic Channel Allocation) algorithm will decide on the basis of mutual interference which band it is to use.

Due to the properties of TDMA one user is only active for a short time within a frame. These activity periods depend on the number of time slots accommodated within one frame, e.g. UMTS standard defines 16 time slots (TS) within a 10ms frame, i.e. 8 TS for Tx as well as 8 TS for Rx. Figure 4 illustrates the partitioning of the users within the TD-CDMA band/frame and points out that most of the time the mobiles are idle.

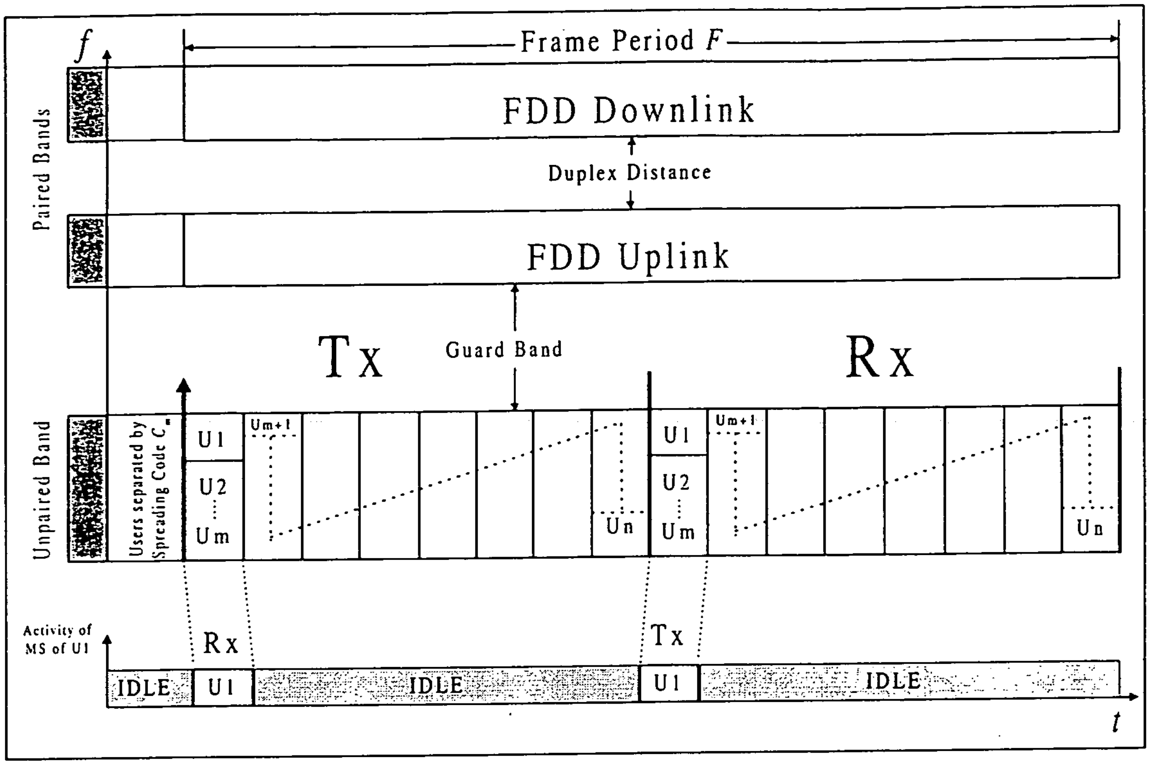

Figure 4: Activity on the unpaired band assigned to users U1-Un. Explicitly the activity of user U1 spread over time *t* is shown. Users U1-Um share the same TS separated by an individual spreading Code *C*. Each user is only active for 7/8 of the time assuming in total 16 time slots. Whereas the FDD users occupy the whole frame of the paired band with instantaneously transmitting and receiving at the same time. Again user separation is achieved by individual spreading codes.

Applying the idea of making use of spare capacity within the FDD band the situation evolves as shown in Figure 5.

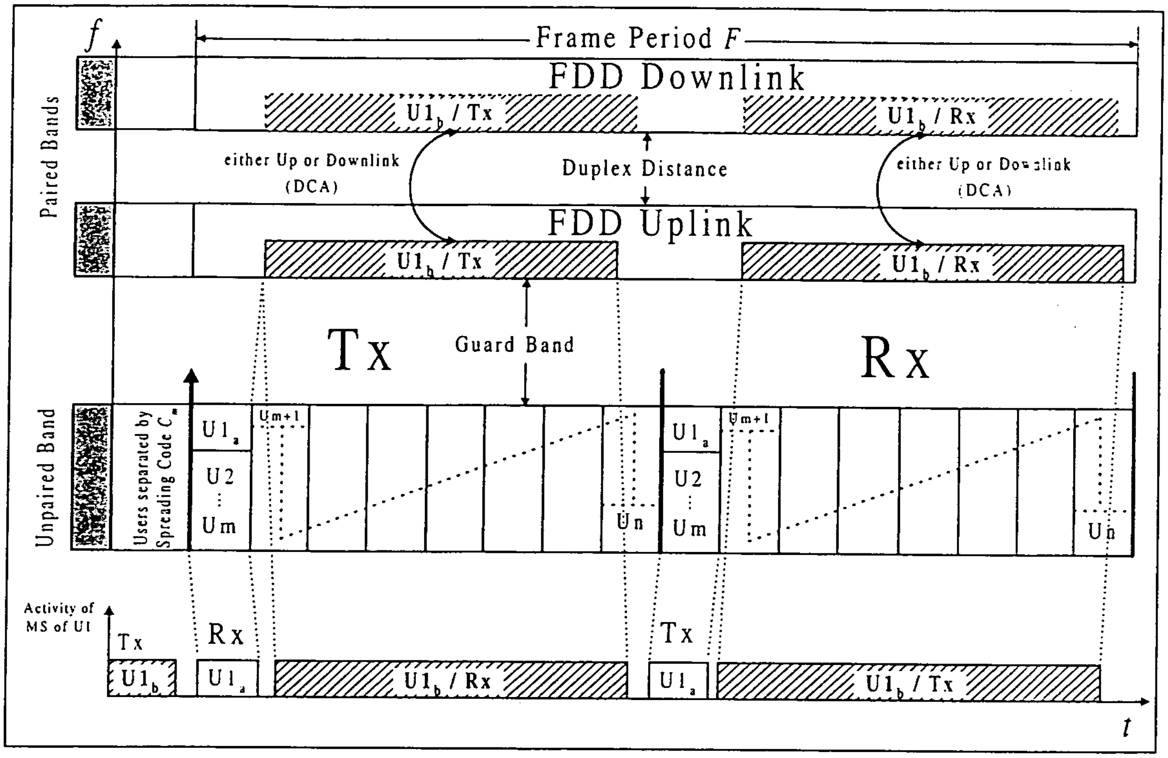

Figure 5: As an example the activity of user U1 is depicted, now, using the idea of exploiting unused FDD bandwidth without affecting the FDD system itself. For demonstration purpose user U1 is logically divided into a part *a* which is related to the previous situation as shown in Figure 4 and a part *b* which is the actual invention.

With the proposed method the logical user $U1_b$ causes some additional interference within the FDD band. Clearly, there is no link to the BS_F. If the TDD cell is properly separated from the BS_F by walls of a building or by distance, denoted as r_b in Figure 1, this additional interference will not greatly affect any FDD link. Furthermore, since there are two potential bands for placing the additional TDD link a dynamic channel allocation (DCA) algorithm can be employed to choose the band resulting in least mutual interference, considering the four possible instances (MS_T, BS_T, MS_F, BS_F). This in most cases will be the uplink band. In the case of using the downlink band it is easy to see that the jammed instance is the FDD cell mobile. Due to its mobility the likelihood of causing outage[6] to it is relatively high when it moves into the TDD cell area. Assuming the FDD cell mobiles to have higher priority in terms of QoS (Quality of Service) this outage can be considered to be more severe than the outage for the TDD instances. However in our example, TDD cell outage only implies that the additional capacity of $U1_b$ is lost. $U1_a$ suffers no outage. It can be gathered from Figure 5 that the TDD cell can be easily combined with only the TDMA scheme. In this case each time slot would just accommodate one user. The next section will introduce the case where the TDD mode is only combined with CDMA.

[6] Outage is where the interference is getting too high so that the BS or MS lose their connections and the call or even all calls are being dropped.

2.2 Illustrating the idea with TDD cells only applying CDMA

So far, it has been shown that the invention can be applied for the cases where the TDD cells employ TDMA-CDMA and TDMA. Now it is considered that the TDD mode is combined with CDMA. The principles for this case are depicted in Figure 6.

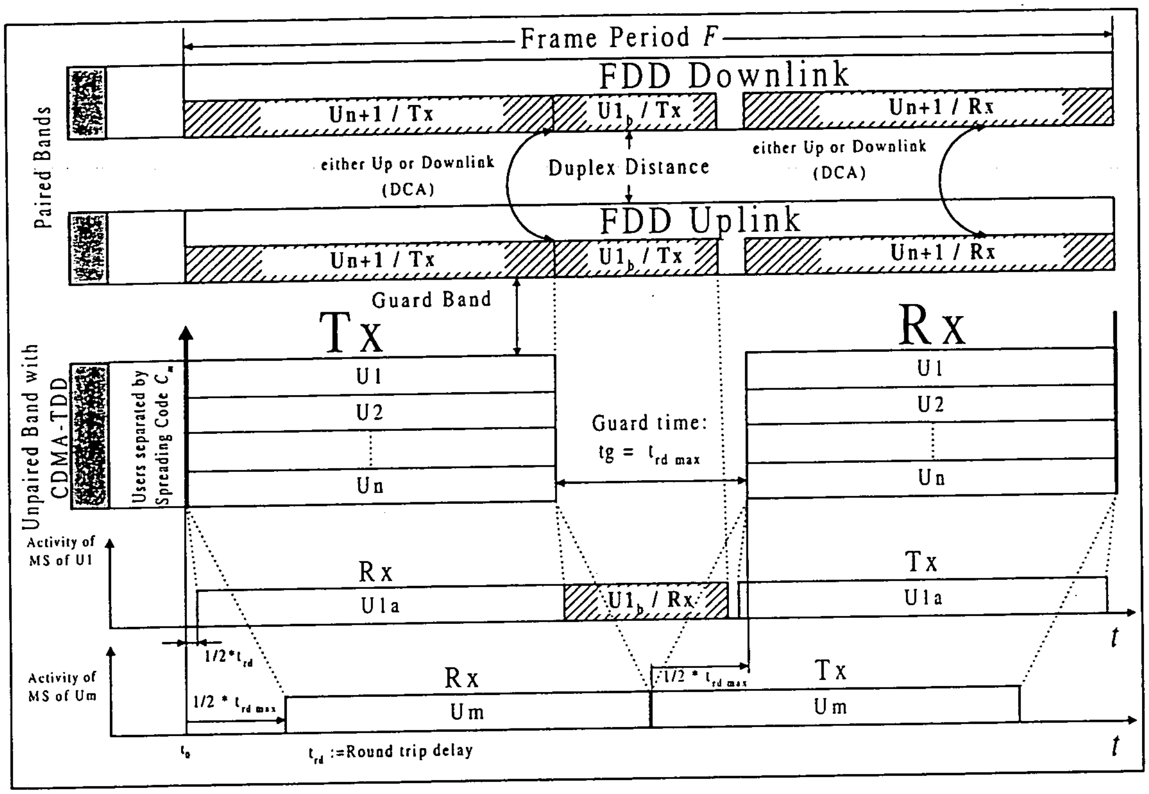

Figure 6: The TDD cells employ CDMA. In this case a guard time has to be introduced in order to avoid collisions between Tx slots and Rx slots because there are delays due to signal propagation and signal processing. These delays are summarised and referred to as round trip delay. The maximum round trip delay is caused by a mobile located at the cell boundary. This is represented by user Um. As an example user U1 is assumed to be closer to the BS resulting in less round trip delay.

As it can be seen from Figure 6 the spare FDD capacity is exploited in two ways:

a) an additional TDD user is served. Since capacity within the FDD band can not guaranteed at any time this link is supposed to have very low priority. That means it is suitable for a packet oriented data service which does not require a guaranteed response time.

b) The guard time resulting from the maximal possible round trip delay which, in turn, mainly depends on the cell size represents a waste of channel capacity. As it can be seen a mobile being closer to BS can make use of the FDD bands while the guard time is active. Thus it can compensate the guard time which results in higher data throughput. However the time to re-program the synthesiser in the RF front end might cause some loss in transmission time. Hence, this operation is only beneficial if the maximal guard time is longer than it takes the mobile for switching the frequency

bands. On the other hand, the necessity to keep the guard times as small as possible is not as strict as before. Thus the cell radius of the TDD cell might be increased without having a major reduction in bandwidth efficiency.

3 Research Results Corroborating the Feasibility of the Invention

3.1 Calculating the interference power at the BS of the TDD system caused by randomly distributed FDD mobiles

Taking a cell topology as shown in Figure 1 up to N mobiles M_j, where $j=1..N$, have been equally distributed. We assumed the additional TDD link to be placed within the FDD uplink band. In this case a FDD mobile can cause outage to the TDD base station BS_T. Under the worst case assumption that the FDD subscriber is talking continuously on the uplink (voice activity of 100%) investigation have been carried out to get the number of additional TDD links which can be placed into the uplink band tolerating a certain outage of the TDD cell. This outage was defined to be 5%, i.e. under the assumption of spatially uniform distributed FDD users 5% out of all observations will cause the BS_T to be intolerably high jammed.

We, first, considered one mobile to be randomly distributed within the FDD cell area. Due to this random location two independent random variables can be established. The pdfs[7] of these variables can be derived from the cell geometry. Afterwards both variables are transformed to a random variable of the received power at the BS_T caused by the FDD mobile MS_F. This transformation takes the assumed signal propagation model into account. The principle of generating the pdf of the random variable assigned to the interference power is depicted in Figure 7.

[7] Pdf stands for probability density function

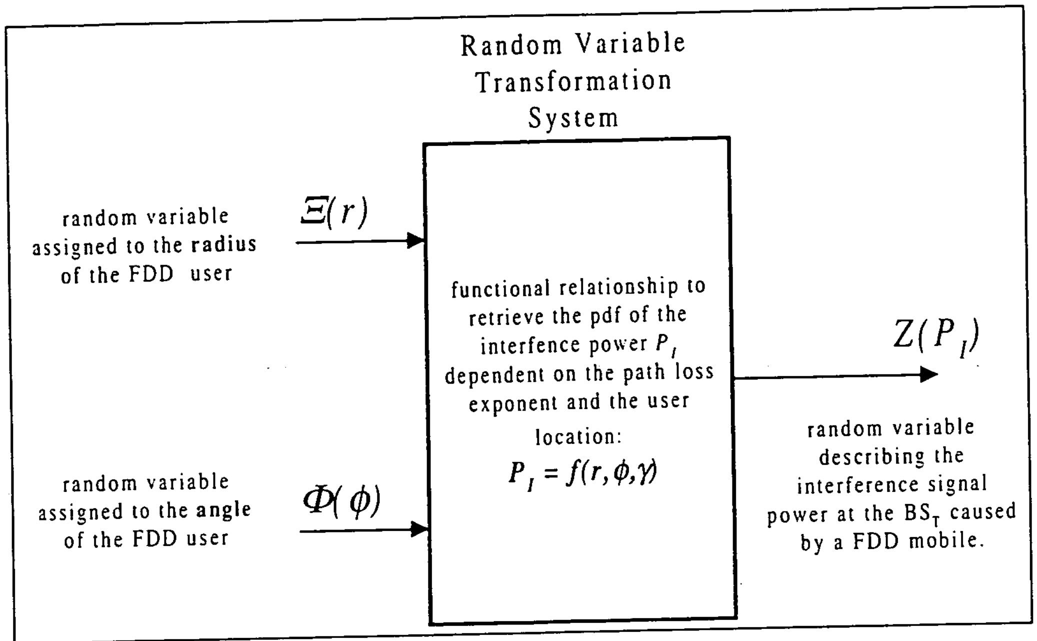

Figure 7: Method of getting the pdf of the interference power at the BS_T caused by a FDD mobile MS_F

After calculating the pdf of Z the scope of the investigation can be extended to N FDD users. Again, this situation is schematically outlined in Figure 1. This leads to a new random variable as follows:

$$S = \sum_{j=1}^{N} Z_j \tag{1}$$

Where S represents the sum of all interference generated by N FDD mobiles. The pdf of S can be found by a N-fold convolution of the pdf of one FDD interferer. This can be written as

$$p(s) = p(P_I) = p_1(z) * p_2(z) * \ldots * p_N(z) \tag{2}$$

where $*$ denotes the convolution operator and P_I represents the total interference power. Finally the cdf[8] of the total interference is found by integration as shown below

$$F(s) = F(P_I) = \int_0^s p(s)\, ds \tag{3}$$

[8] cumulative density function

Now it is possible to calculate $\tilde{P}_I$ which has the property that the probability of getting higher interference than $\tilde{P}_I$ is less than a defined outage threshold, e.g. 5%. Figure 8 shows this graphically.

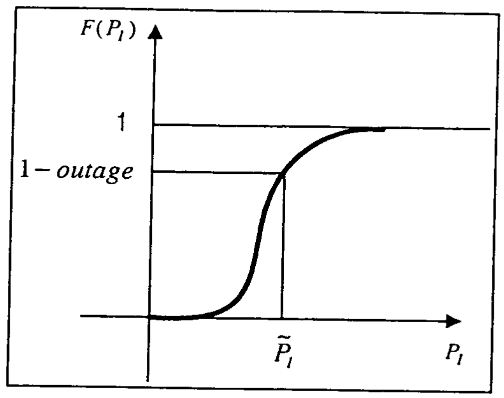

Figure 8: Getting $\tilde{P}_I$ so that $F(\tilde{P}_I) = 1 - outage$

3.2 Calculating the additional of capacity within the TDD cell

The carrier to interference ratio (C/I) is a main parameter to calculate the capacity of CDMA system. Its threshold is mainly determined by the multiple access scheme, the equalisation and coding techniques in the baseband. The following general equation can be denoted for a CDMA system:

$$C/I = \frac{P_\mu}{P_\mu(M_\mu - 1) + \tilde{P}_I} = \frac{1}{(M_\mu - 1) + \frac{\tilde{P}_I}{P_\mu}} \qquad (4)$$

where P_μ is the desired power from the TDD mobile received at the BS_T (The subscript μ is due to the fact that the TDD cell is often used as a underlayed microcell). It is assumed that all TDD mobiles are run with ideal power control in the uplink so that P_μ is constant for each MS_T. M_μ is the number of TDD mobiles exclusively located into the FDD uplink band, i.e. those parts denoted as $U1_b$ in Figure 5. The capacity in the main unpaired band will not be affected. Therefore M_μ is just the number of additional links and thus additional capacity in terms of throughput. With the parameters given in Table 1 simulations have been carried out to, firstly, calculate $\tilde{P}_I$ and subsequently feeding $\tilde{P}_I$ into equation (4) to obtain M_μ dependent on the number of FDD mobiles. P_μ can be calculated because the propagation conditions as well as the transmission power of the MS_T are known. Pr_μ was chosen so that the FDD cell capacity will not be affected assuming the base station separation distance r_b is more than about 400m. This assumption is done under worst case conditions. Despite this, the plots in Figure 9 also show the results with *rb < 400m*.

Table 1: Parameters used for simulation

Description	Parameter	Value	Unit
Radius of FDD cell	R	1000	m
Wavelength	λ	0.15	m
Reference power at FDD cell boundary	P_R	2.5	W
Radius of TDD cell	R_μ	120	m
Reference power at TDD cell boundary	Pr_μ	2.90	mW
Path loss exponent	γ	4	

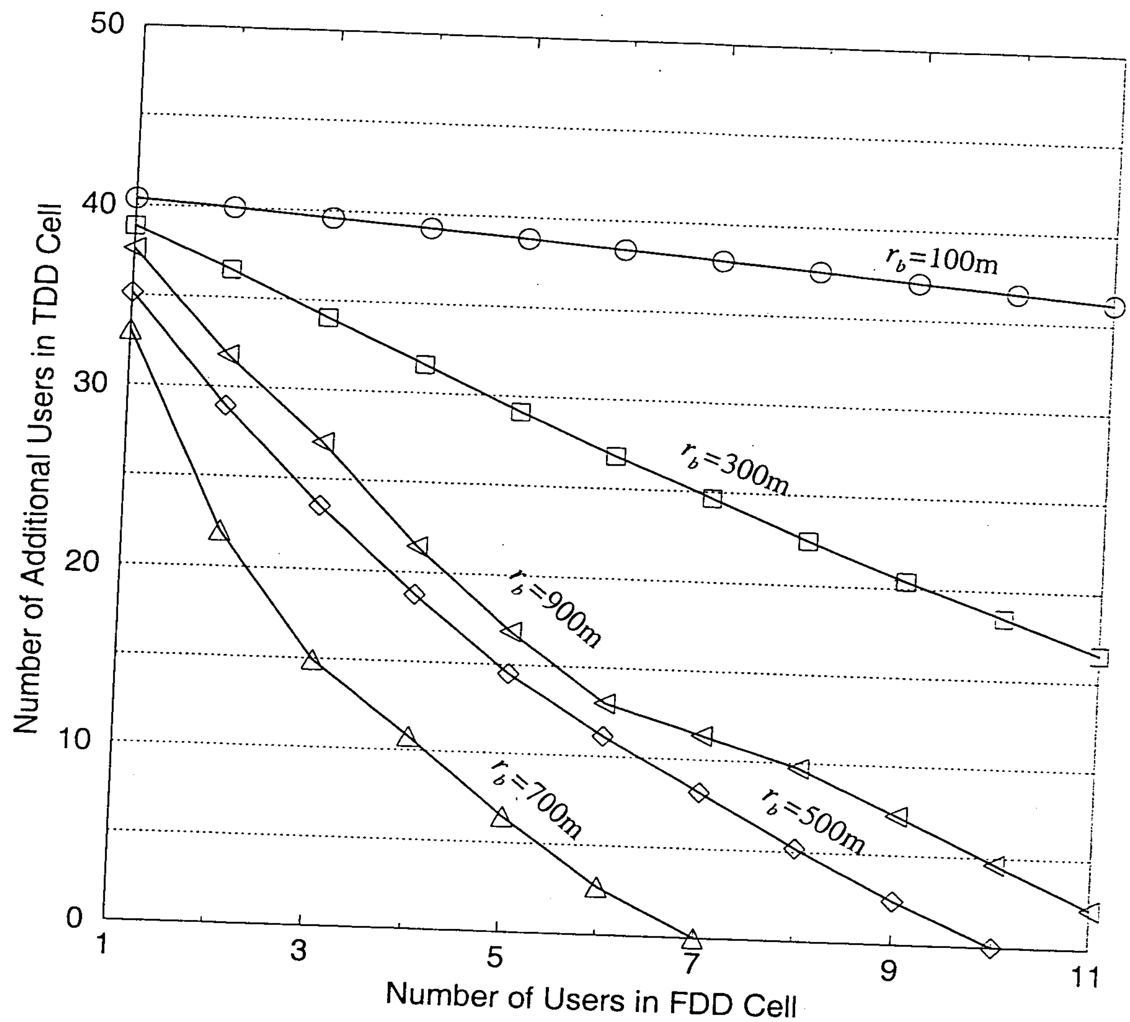

Figure 9: Additional capacity within the TDD cell, using the FDD uplink band, dependent on the number of active FDD links and the distance between BS_T and the BS_F

3.3 Discussion of the simulation results

The results for *rb=100m* and *rb=300m* are, in this case, of minor interest because there is some evidence that the FDD cell system might be intolerably jammed under some worst case conditions.

The result for *rb=900m* reveals some abnormal behaviour. This is due to the cell boundary effect, because this model consists only of one FDD cell. Hence the interference from adjacent cells is neglected causing above mentioned cell boundary effect.

The real interesting results are for *700m < rb < 400m*. If the BS_T is placed inside this area and the FDD mobiles are equally distributed there is additional capacity available in the FDD uplink band when there are statistically less than 10 FDD mobiles active at the same

time. The tolerated outage for the TDD cell, as defined in section 3, is assumed to be 5%. Clearly, this outage does not affect the communication links in the TDD unpaired band itself.

The results of the simulations point towards a significant gain. Placing the BS_T. for example, at a radius of *rb=500m* and assuming 5 active FDD mobiles there are additional 15 TDD links available within the TDD cell. This now available capacity can be shared between the TDD users, e.g. increasing the data rate of one user, for example U1, 15 times. Considering a total capacity of the FDD system of about 15 users the average gain in capacity can be expressed in relative terms. That means with about 30% load of the FDD system the TDD cell can convert the unused radio resources to extend its own capacity by approximately 40%.

The benefits become much more apparent when considering more than one TDD cell within the FDD cell area. In this case the reuse of the FDD band is again increased resulting in further bandwidth efficiency, but it must be stated that interference from adjacent FDD cells might reduce the capacity gains slightly. However, on the other hand applying a more realistic voice activity which is about 3/8 the latter negative influence will be at least compensated in a spread spectrum system.

The simplification of assuming spatially uniform distributed FDD mobiles does not hold in any real environment, and the results given in Figure 9 imply an averaging over infinite user distributions. Hence, there are individual constellations allowing even more simultaneously active FDD users than the calculated numbers and still having spare capacity in the FDD band. On the other hand the actual distribution at a certain time can be worse resulting in less capacity in the FDD band than shown in Figure 9.

3.4 Conclusions and Summary

The invention offers the possibility to achieve a flexible use of the frequency bands assigned to different duplex and access schemes. It has been proved that a TDD system can convert unused bandwidth of a FDD system to increase the overall bandwidth efficiency which in turn results in a higher data throughput.

Regarding the practical realisation it can be stated that the additional hardware and software efforts in the mobile unit are minimal because, on the one hand, the hardware blocks for transmitting on the FDD uplink may already exist. On te other hand the mobile is capable of using the TDD scheme within the unpaired band. Finally, it is just a combining of both existing functionalities. Hence, the additional costs for implementing this system are marginal whereas the gain in bandwidth efficiency is significant. However, to obtain the full efficiency the TDD base stations should ideally be located at a distance of about half the FDD cell radius.

If the BS_T station is able to transmit and receive at the same time on different frequencies the additional capacity at the FDD band might only be used in the reception direction (e.g.

for file downloads from the Internet). This means that the suggested method can be used to assign channel asymmetry to an individual TDD user in a TD-CDMA system which would represent another novelty as a consequence of the proposed idea.

The advantages of this invention have be demonstrated on systems combining the TDD mode with:

- TDMA/CDMA
- TDMA
- CMDA

Again, it must be pointed out that this selection is just a subset of all possible multiple access techniques.

In case of applying TDD-CDMA this invention can be used to bridge the gaps resulting from unavoidable guard times in a TDD system. This offers new perspectives for designing TDD cells.

A technique was described how a mobile communications system, using a separated frequency band, can borrow bandwidth from another cellular network. In this paper this was demonstrated on a TDD system which borrows channel capacity from a FDD system by making use of guard times and unused time slots. The FDD system was considered to employ any multiple access method. It is obvious now that the channel borrowing technique can be extended when thinking the other way round. In the same manner as described a mobile assigned to the FDD cell can make use of the unpaired TDD band when it is located at a distinct distance from the micro cell. In addition, the interference problem in this case is more relaxed because the micro cell network is not supposed to have an overall coverage. Thus there might be large gaps in the coverage area of the mobile communications network where the TDD mode is not used resulting in a waste of bandwidth. So, there is enough evidence for the FDD mobile to get additional radio resource to increase its data throughput. The only major difference from the previously described direction of borrowing is that the FDD mobile will use the additional unpaired band for either the uplink or the downlink and not for both together. Hence the proposed technique is an ideal way to achieve channel asymmetry within an FDD system.

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